HADRONIC FLUCTUATIONS AND QUARK-ANTIQUARK ASYMMETRY IN THE NUCLEON [a]

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We derive the nucleon non-perturbative sea-quark distributions coming from a composite model involving quarks and hadronic degrees of freedom. The model predicts a definite structured $q - \bar{q}$ asymmetry in the nucleon sea.

1 Introduction

The quark-antiquark sea of a hadron is mainly generated in a perturbative way as Q^2 rises up. Nevertheless, it is widely believed that some fraction of the sea quarks may be associated with non-perturbative processes. One of the most important issues of such a prospect is the possibility of having non-symmetric quark-antiquark distributions which could, in principle, be measurable. This is a topical question related to current experiments concerning either light or heavy flavors. For instance, regarding the strange sea of the nucleon, the present status of the experimental data does not exclude the possibility of asymmetric s and $\bar{s}$ distributions. The CCFR Collaboration [1] has analyzed the strange quark distribution in protons allowing explicitly for $s(x) \neq \bar{s}(x)$ distributions. Although the analysis of the above experiment seems to indicate small differences between the two distributions, the error bars are still large to be conclusive (see also discussion in Refs. [2,3]).

Here we present a novel procedure suitable to calculate quark and anti-quark non-perturbative distributions in the nucleon's sea. Within the framework of the meson cloud picture, we explicitly compute the probability density of having a meson and a baryon inside the nucleon, using splitting functions and recombination models. The quark and anti-quark non-perturbative distributions in the parent nucleon are obtained by means of the convolution of the meson and baryon probabilities with the corresponding s and $\bar{s}$ distributions inside baryon and meson respectively.

2 The $q - \bar{q}$ asymmetry in the nucleon's sea

We start by considering a simple picture of the nucleon in the infinite momentum frame as being formed by three dressed valence quarks so-called valons[4],

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$v(x) = \frac{105}{16}\sqrt{x}\,(1-x)^2$. In the framework of the meson cloud model, the nucleon can fluctuate to a meson-baryon bound state carrying zero *net* extra flavors. As a first step in such a process, we may consider that each valon can emit a gluon which before interacting decays perturbatively into a $q\bar{q}$ pair. The probability of having such a perturbative $q\bar{q}$ pair can be evaluated in terms of the Altarelli-Parisi splitting functions, $P_{gq}(z) = \frac{4}{3}\frac{1+(1-z)^2}{z}$, $P_{qg}(z) = \frac{1}{2}\left(z^2 + (1-z)^2\right)$, giving the probability of gluon emision and $q\bar{q}$ creation with momentum fraction z from a parent quark and gluon respectively. Hence,

$$q(x,Q^2) = \bar{q}(x,Q^2) = \frac{\alpha_{st}^2(Q^2)}{2\pi^2}\int_{x+a}^1 \frac{dy}{y} P_{qg}\left(\frac{x}{y}\right) \int_y^1 \frac{dz}{z} P_{gq}\left(\frac{y}{z}\right) v(z) \quad (1)$$

is the joint probability density of obtaining a perturbative quark or anti-quark coming from subsequent decays $v \to v + g$ and $g \to q + \bar{q}$ at some fixed low Q^2 scale. We have introduced a cut-off, a, in order to suppress the divercence at $x = 0$ in the gluon distribution given by the inner integral (see also Ref.[5]). We fixed it by requiring that the quark distributions given by eq. (1) lay below experimental data [6] at a common scale. The range of values of Q^2 at which the process of virtual pair creation occurs is dictated by the valon model of the nucleon. For definiteness, we here use [4] $Q = 0.8$ GeV, for which α_{st} is still sufficiently small to allow the perturbative evaluation of the $q\bar{q}$ pair production. Once a $q\bar{q}$ pair is produced, it can rearrange itself with the remaining valons so as to form a most energetically favored meson-baryon bound state. The evaluation of meson and baryon formation has to be made using effective techniques in order to deal with the non-perturbative QCD processes involved in the dressing of quarks into hadrons. Although in-nucleon meson and baryon are virtual states, one may assume that the mechanisms involved in their formation are similar to those at work in the production of real hadrons in hadronic collisions; then, we can evaluate the $N \to MB$ fluctuation by means of a well-known recombination model approach. To ensure zero net extra flavors in the nucleon, as for momentum conservation, we may assume that the in-nucleon meson and baryon distributions satisfy $P_M(x) = P_B(1-x)$. Now, we can for instance proceed to compute the strange meson distribution $P_M(x)$ along the lines of Ref. [7] and then relate it to the hyperon probability as indicated above (see Fig.1a) [b]. Now, the non-perturbative strange and anti-strange sea distributions can be computed by means of two-level convolution formulas [3]

$$s^{NP}(x) = \int_x^1 \frac{dy}{y} P_B(y)\ s_B(x/y) \qquad \bar{s}^{NP}(x) = \int_x^1 \frac{dy}{y} P_M(y)\ \bar{s}_M(x/y), \quad (2)$$

[b] The overall normalization is given by the probability that the strange hadronic fluctuation occurs; this value is commonly supposed to be around $4-10\%$ (see *e.g.* Refs.[2]).

where the sources s_B and $\bar{s}_M$ are primarily the momentum distributions of the valence quark and anti-quark in baryon and meson respectively at the hadronic scale Q^2. The most likely meson-baryon configurations are those closest to the nucleon energy shell, namely ΛK and ΣK.

As long as experimental measurements are lacking at present, several choices are possible for the $\bar{s}_M$ and s_B distributions in K-ons and Λ, Σ baryons respectively. In this respect, it is a common practice to employ modified light valence quark distributions of pions and protons [3]. However, we think that one should better use simple forms reflecting the fact that strange quarks carry a rather large amount of momentum in $S = \pm 1$ hadron states at low Q^2. Indeed, $\bar{s}_M(x) = 6x(1-x)$ adequately reflects this feature and, additionally, it reproduces quite well the momentum distribution found by Shigetani *et al.* [8] in the framework of a Nambu-Jona Lasinio model at low Q^2. For similar reasons, in Λ and Σ baryons we expect a s momentum distribution peaked around 1/2, which after normalization can be written as $s_B(x) = 12x(1-x)^2$. The non-perturbative s and $\bar{s}$ distributions of eqs. 2 as well as the corresponding $s - \bar{s}$ asymmetry are shown in Fig. 1b and 1c respectively.

3 Summary and discussion

We based our approach on a valon description of the ground state of the nucleon, which perturbatively produces sea quark/anti-quark pairs giving rise to a hadronic bound state by means of recombination with the remaining valons. In this way, a specific connection between the physics of hadronic reactions and that of hadron fluctuations is established. This is an important point of the approach since the physical principles related to confinement in QCD should be common to both processes. It is interesting to note that neither nucleon-meson-hyperon coupling constants nor vertex functions are needed for taking into account the extended nature of the nucleon-meson-hyperon vertex, avoiding the use of these controversial ingredients.

As we have shown in Fig. 1c, the model predicts a definite structured asymmetry in the strange sea of the nucleon. The shape of the s and $\bar{s}$ distributions as well as their difference are similar to those found in a recent analysis based on a different approach [2]. One should notice that the predicted non-perturbative quark and anti-quark distributions depend on the form of the valence quark and anti-quark distributions of the in-nucleon baryon and meson respectively. So, although the model is reliable in predicting different distributions for sea quark and anti-quarks, their exact shapes remain unknown until we have more confident results for valence densities inside strange hadrons. Nevertheless, the model predicts an excess of quarks over anti-quarks in the nucleon sea carrying a large fraction of the nucleon's momentum (see Fig. 1c) and this prediction appears to be independent of the exact form of the strange

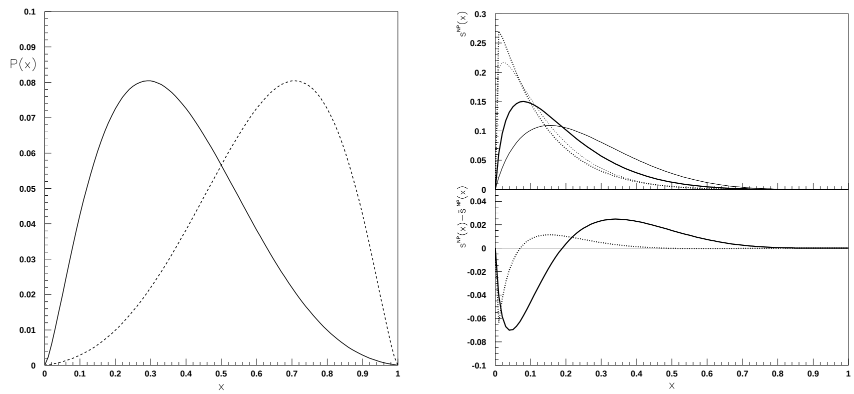

Figure 1: Left: a) Meson (full line) and baryon (dashed line) probability densities in the nucleon. Right: b) Full lines are s^{NP} (thin) and $\bar{s}^{NP}$ (thick), as obtained by using our simple forms for s_B and $\bar{s}_M$. Point lines result of using, instead, light-like distributions. c) The corresponding $s(x) - \bar{s}(x)$ asymmetries. See Ref. 5 for more details.

and anti-strange distributions inside the in-nucleon baryon and meson.

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References

1. A.O. Bazarko *et al.* (CCFR Collaboration), *Z. Phys.* C **65**, 189 (1995).
2. S.J. Brodsky and B.Q. Ma, *Phys. Lett.* B **381**, 317 (1996).
3. A. Signal and A.W. Thomas, *Phys. Lett.* B **191**, 205 (1987).
4. R.C. Hwa, *Phys. Rev.* D **22**, 759 (1980); *ibid.* 1593.
5. H.R. Christiansen and J. Magnin, *Strange anti-strange asymmetry in the nucleon sea*, hep-ph/9801283, to appear in *Phys. Lett* B.
6. M. Glück, E. Reya and A. Vogt, *Z. Phys.* C **53**, 127 (1992).
7. K.P. Das and R.C. Hwa, *Phys. Lett.* B **68**, 459 (1977).
8. T. Shigetani, K. Suzuki and H. Toki, *Phys. Lett.* B **308**, 383 (1993). J.T. Londergan *et al. Phys. Lett.* B **380**, 393 (1996).